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Variation of Flux in Membrane Distillation

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Abstract

The objective of this review is to study briefly the membrane distillation in desalination application and effects of various process parameters such as feed temperature, feed flow rate and feed concentration on permeate flux. Several studies about the variation of flux have been reviewed in this paper. The review also covers the concept of fouling in membrane distillation.

Keywords: Permeation flux enhancement, process parameters , fouling.

1. Introduction

Membrane distillation (MD) is a thermally driven desalination process that involves phase conversion from liquid to vapor on one side of the membrane and condensation of vapor to liquid on the other side [1]. The exploitation of waste heat energy sources such as solar energy enables MD more promising separation technique for industrial scale. Growing economics and water scarcity are driving desalination as a solution for water supply problems. Membrane distillation in the application of water desalination make this technology a prospective one in the research areas. The membrane facilitates the transport of water vapor through its pores but does not participate in the actual separation process. Membrane distillation can be employed in four different configurations namely DCMD, AGMD, VMD and Sweeping gas membrane distillation. Those of which DCMD and AGMD are best suited for the desalination applications where water is the major permeate component. These two configurations are applied to produce fresh water from a salt solution [2].

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2. MD Configurations

2.1. Direct Contact Membrane Distillation (DCMD)

In this configuration, the hot solution (feed) is in direct contact with the hot membrane side surface. Therefore, evaporation takes place at the feed-membrane surface. The vapour is moved by the pressure difference across the membrane to the permeate side and condenses inside the membrane module.

2.2. Air Gap Membrane Distillation (AGMD)

Here the feed solution is in direct contact with the hot side of the membrane surface only. Stagnant air is introduced between the membrane and the condensation surface. The vapour crosses the air gap to condense over the cold surface inside the membrane cell. The benefit of this design is the reduced heat lost by conduction.

2.3. Vacuum Membrane Distillation (VMD)

In VMD configuration, a pump is used to create a vacuum in the permeate membrane side. Condensation takes place outside the membrane module. The heat lost by conduction is negligible, which is considered a great advantage.

2.4. Sweeping Gas Membrane Distillation (SGMD)

In Sweeping Gas Membrane Distillation (SGMD) inert gas is used to sweep the vapour at the permeate membrane side to condense outside the membrane module. There is a gas barrier, like in AGMD, to reduce the heat loss, but this is not stationary, which enhances the mass transfer coefficient, [2,3] .

3. Advantages of MD

The advantages of MD process are , it can be performed at lower operating temperatures and pressure. It requires lower vapor space, unlimited by high osmotic pressure and fouling. MD permits very high separation factor of non-volatile solute and has potential applications for concentrating aqueous solutions or producing high-purity water, and it can use any form of low grade waste heat and can be coupled with solar energy systems. [3,4]

4. Results & Discussion

4.1. Influence of operating parameters on flux

In this section, the influence of feed temperature, concentration and the flow rate will be reviewed and major findings will be cited and discussed.

4.2. Effect of Feed Temperature

Here the effect of flux changes by means of changing the hot feed temperature at a constant feed flow rate and concentration of the solution. The permeate flux increased with increasing temperature.

Table 1. Effect of feed temperature on flux .

References	Module Type	Feed	Feed Temp. range K	Feed Flow rate l/hr	Flux (kg/m^{2}hr) ≈
[5]	VMD	Aq. Nacl(6%)	318.5-334.5	4.63x10^{-3}	7-12
[6]	DCMD	Salt water	290.5-300.5	57.6	0.25- .144 x10^{-3}
[7]	DCMD	Pure water	307-343	18.3x10^{-3}	5.33-58.05
[8]	AGMD	Ground water	313-333	55	20-38
[9]	DCMD	Orange Juice	313-353	72	7.2-31.13
[10]	DCMD	Water	303-333	17.5x10^{-3}	4 -26 (PP22)
[11]	AGMD	Water	333 - 363	3	0.5 - 2.8
[12]	DCMD	Water	333 - 363	3.1x10^{-3}	6.17-18.8

From the table.1, it is inferred that feed temperature has a strong influence on distilled flux. Most of the researchers show that permeation flux of VMD process increases obviously with increasing of feed liquid temperature at the same operational condition. The main driving force is pressure difference across membrane in VMD process. The feed temperature increases, making vapour pressure of gas-liquid interface on liquid feed side increases when temperature increases, the driving force of mass transfer increases accordingly[5,6].The flux enhancement was due to the difference in the membrane thickness [10]. The experimental flux increases at various feed temperature corresponded with the flux from molecular diffusion model [7]. The flux enhancement can be achieved by the surface modification of membrane by treating with alcohol in AGMD for desalination of ground water [8]. The increase in flux by using capillary membrane, which acts as static mixer improves the efficiency [12].

4.3. Effect of Feed Flow Rate

The effect of the feed flow rate was studied under the conditions of a constant initial concentration of the feed solution, feed temperature of the hot solution and coolant temperature. The permeate flux increased rapidly and seemed to reach maximum values asymptotically for higher feed flow rates [10,14].

Table 2. Effect of Feed flow rate on flux obtained from several studies reviewed in this paper.

References	Range of feed flow rate – l/hr	Feed temp K	Flux Kg/m^2 hr ≈
[5]	2-5x10^{-3}	323.15	4-7
[8]	38-60	333	28-40
[9]	30-75	323	5-10
[10]	7-21x10^{-3}	313	10 – 13
[13]	1.5-6	298	8 %
[14]	30-55	313	10-14

From table 2.The results shown by many researchers are, the permeation flux of aq.Nacl solution in VMD was influenced by not only the membrane morphology but also the feed flow condition [5]. The flux increment of 69% with increase of feed flow rate for treated membrane than non-treated membrane [8]. The flux increases with increasing flow velocity, that may be due to the enhanced mixing, increased permeability and decrease in the thickness of the temperature boundary layer[10].The flux is not affected by the feed flow rate at low concentration, in case of higher concentration(phycocyanin), 8% increase of flux was observed[13].

4.4. Effect of feed concentration

The results from table 3 show that the decrease in flux with the increase in feed concentration found by many researchers.

Table 3. Effect of feed concentration on flux

References	Feed concentration (g/l)	Feed flow rate l/hr	Temp. K	Flux Kg/m^2 hr ≈
[5]	29-70	4.63x10^{-3}	323.15	12-7
[6]	58.4-110	57.6	294.5	10.1-7.2
[9]	80-200	72	333	20-8
[10]	0.6 - 73	14x10^{-3}	313	15-13
[14]	5-7	55	333	3%

The decrease in flux approximately in a linear way with the varied salt concentration, may be due to the thermodynamic irreversible process [6]. The flux decay with increased feed concentration may be due to the significant increase in juice viscosity [9]. It was assessed Nacl average flux decline of 9% at 73g/l, decrease in flux may be due to the water vapour pressure of water decreases results in low driving force for evaporation [10]. Experimental studies shows the increase of feed concentration of salt from 5 - 7g/l, decrease in the permeation flux, reduction was less than 3%, hence for ground water desalination the feed concentration effect may be negligible[14].

4.5. Membrane fouling

Feed heating leads to precipitation of several compounds on the membrane surface which leads to fouling and scaling on the membrane surface. The deposition on the membrane surface causes reduction of permeate flux, contributes more wettability, damage the membrane surface and decrease the heat efficiency. Thus MD performance was lowered by fouling. There are several types of fouling, which may block the membrane pores. Biological fouling is growth of bacteria on the surface of the membrane and scaling (for the high concentration solution), which will create an additional layer on the membrane surface, composed of the particles present in the liquid, [1]. The pre-treatment and membrane cleaning are the main techniques to control fouling. This process increases the product flux by 25%,which means the process is important in order to enhance the permeate flux and proposed that the fouling intensity can be limited by operating at low feed temperature and increasing the feed flow rate. [2, 15]

4.6. Flux enhancement approach

Permeate fluxes can be significantly be improved by the following factors, by reducing the vapor/air gap thickness from 5 to 1mm increased the flux 2.3 fold ,mass flow rate of feed solution has a smaller effect increasing it 3 fold, increases the flux by about 1.3 fold, concentration of solute has a slight effect, increasing the concentration, by more than 5 fold decreases the flux, cold side condition have low effect on the process than the hot side and reducing the thermal conductivity of the membrane material improves the process efficiency, [2]. Flux can be enhanced in MD by fabrication of dual layer hydrophilic-hydrophobic hollow fiber membranes. Optimization of membrane characteristics such as thickness, pore size and its distribution, surface and bulk porosities and membrane contact angle can highly enhance the obtained in the DCMD process.[16]

5. Solar thermal driven MD

Solar collecting technologies coupled with membrane distillation for sea water desalination demands certain considerations, they are, Solar photovoltaic cell, solar thermal energy conversion efficiency, performance parameters in solar powered MD and coupling MD with solar energy collectors like flat plate, parabolic type and solar stills. Small scale SPMD systems for desalination units suitable to provide water for human needs in remote areas where water and electricity infrastructures are currently lacking [17]

6. Conclusion

It is concluded that the experimental work should be carried out at an optimal conditions to get good permeate flux. Flux enhancement depends upon so many parameters, which requires reliable methods for evaluation. Research should be focused in such a way, the reliability of the process will bring the membrane distillation process into the real world of commercialization than merely experimenting in lab and pilot scale. Hence proving to be the promising technology in the application of sea water desalination, thus quenching the thirst of millions of people living in arid and semi-arid regions. The scope of future study involves the identification of opportunities that maximise the advantages of MD over competing technologies, research can be devoted for newer applications like solar-thermal driven MD, where MD can be promising technology.

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